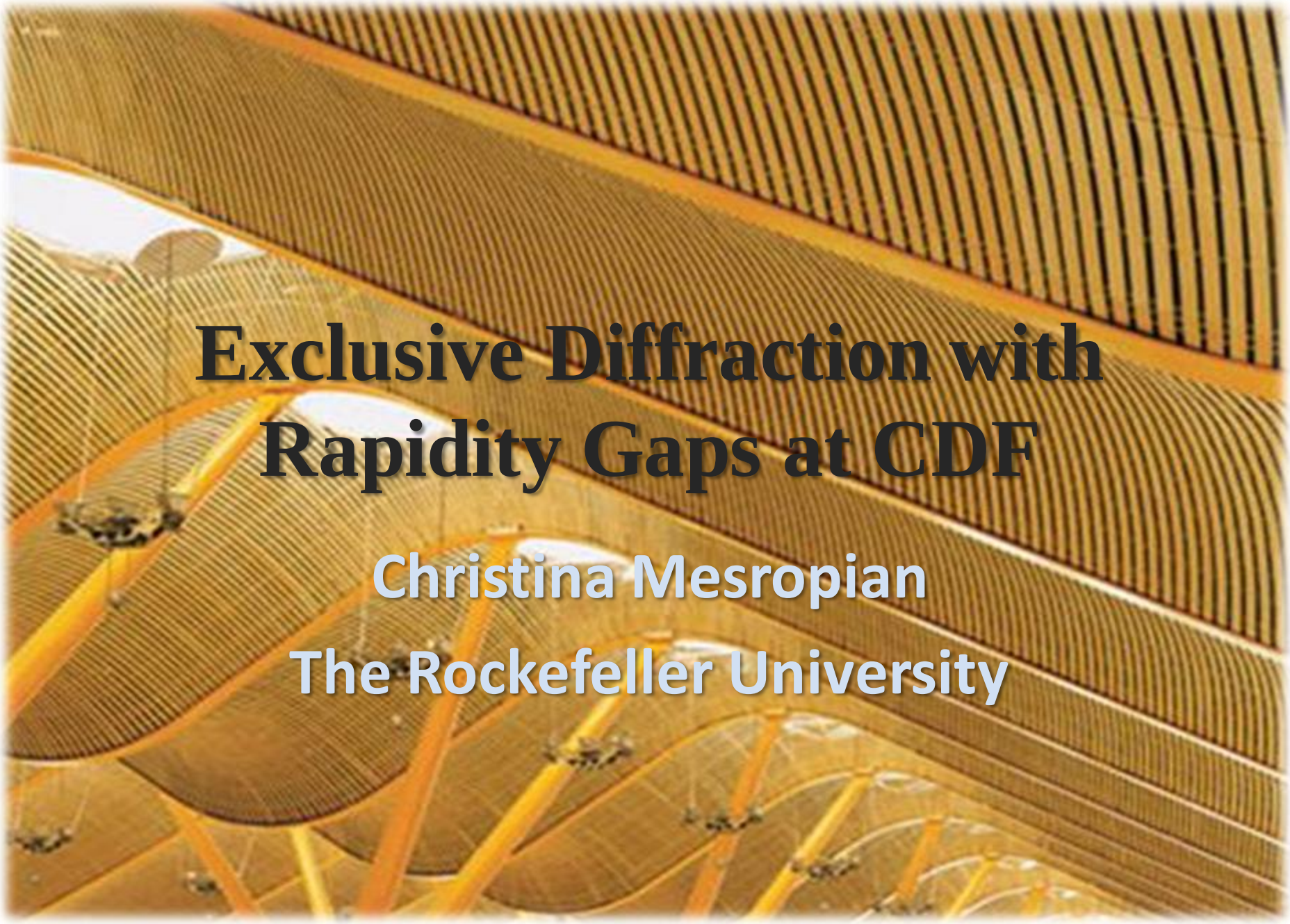
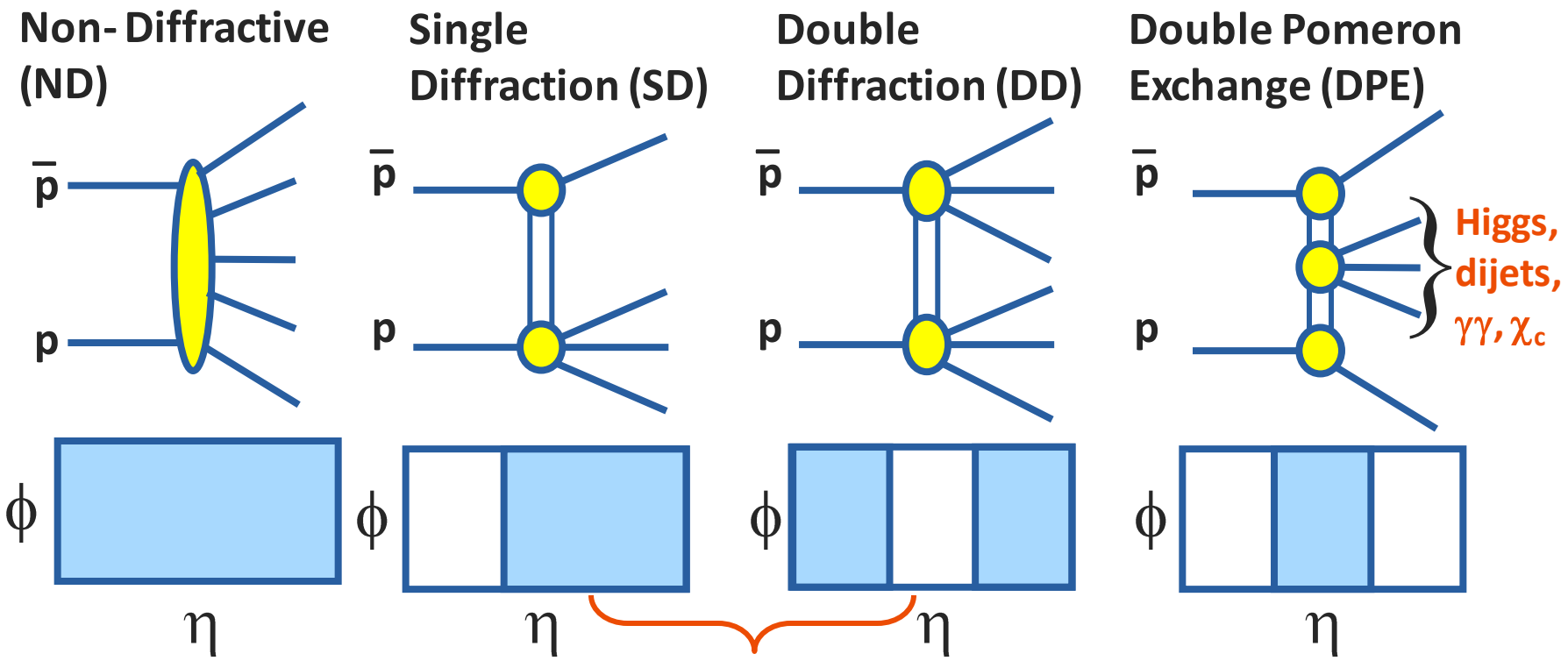


# Exclusive Diffraction with Rapidity Gaps at CDF

Christina Mesropian
The Rockefeller University

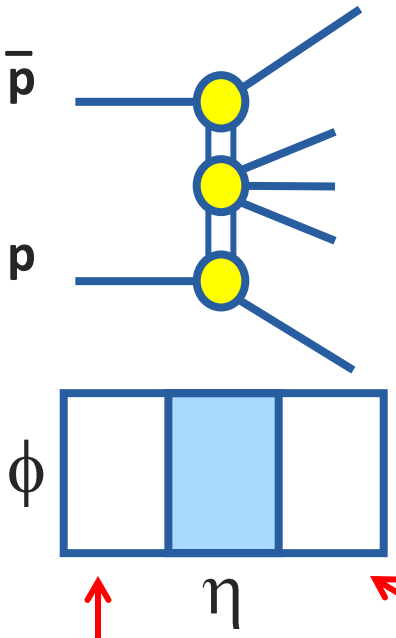
# Introduction

**Diffractive reactions at hadron colliders are defined as reactions in *which no quantum numbers* are exchanged between colliding particles**



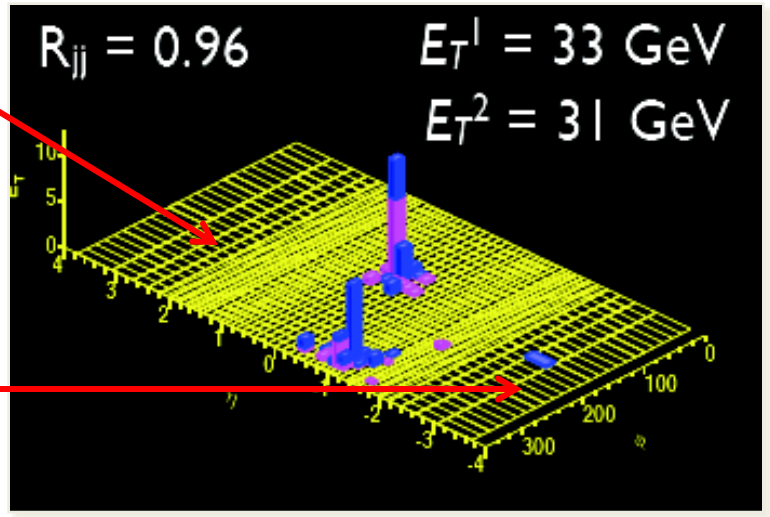

Results discussed in "Diffractive W, Z, dijet, and jet-gap-jet production in CDF"

# Diffraction with Rapidity Gaps




**Alternative definition of diffraction:**

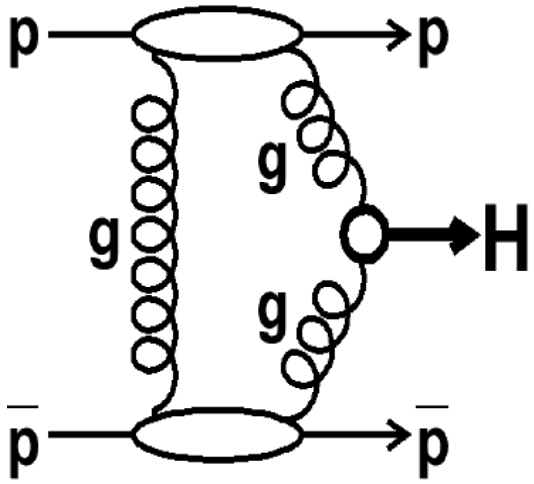
Diffractive reaction is characterized by a
***large,***
***non-exponentially suppressed,***
***rapidity gap***
in the final state.



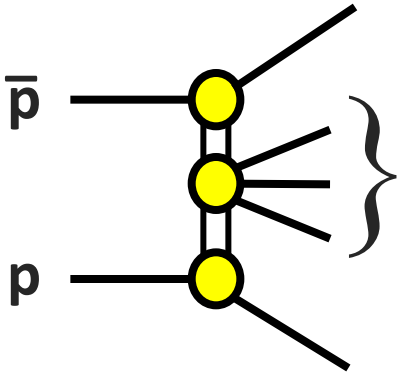

***rapidity gaps***

# Exclusive Production

**Attractive channel for Higgs discovery at LHC**



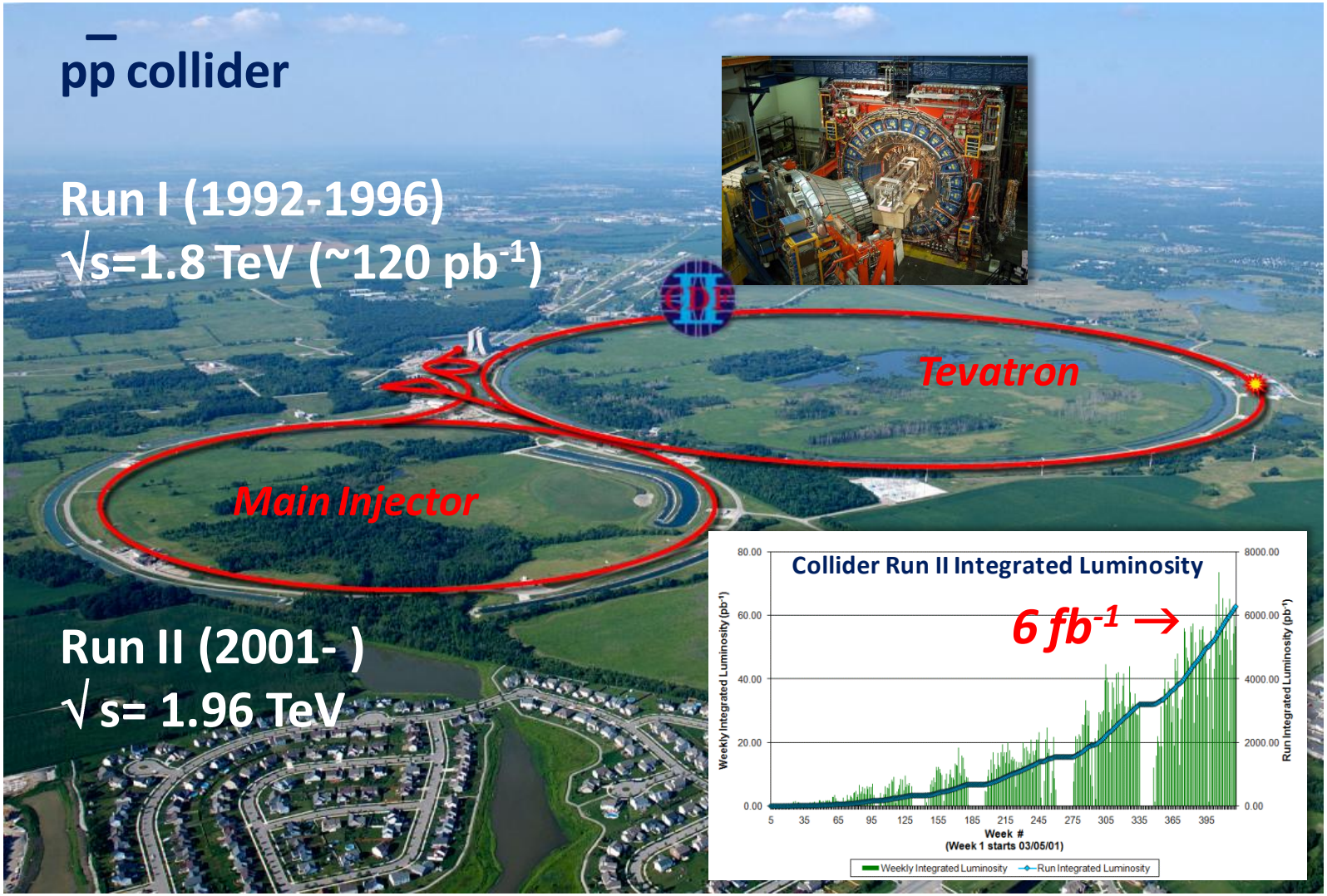

- suppression at LO of the background sub-processes ($J_z$=0 selection rule)
- "exclusive channel" →clean signal (no underlying event)



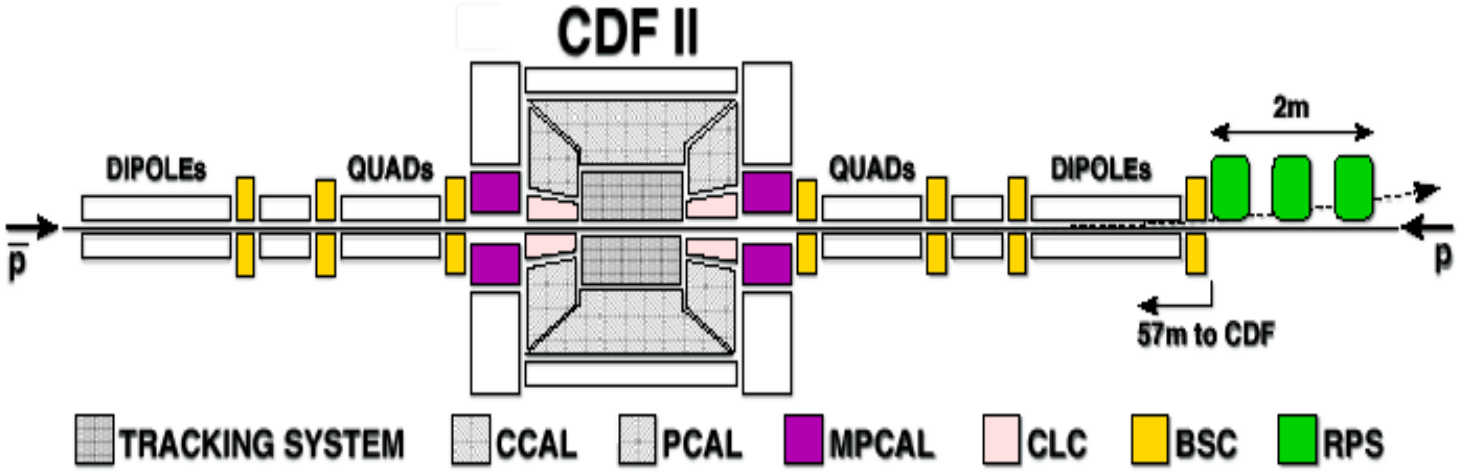

Dijets, $\gamma\gamma$, $\chi_c$

**At the Tevatron we use similar processes with larger cross sections to test and calibrate theoretical predictions**

# Fermilab Tevatron Collider



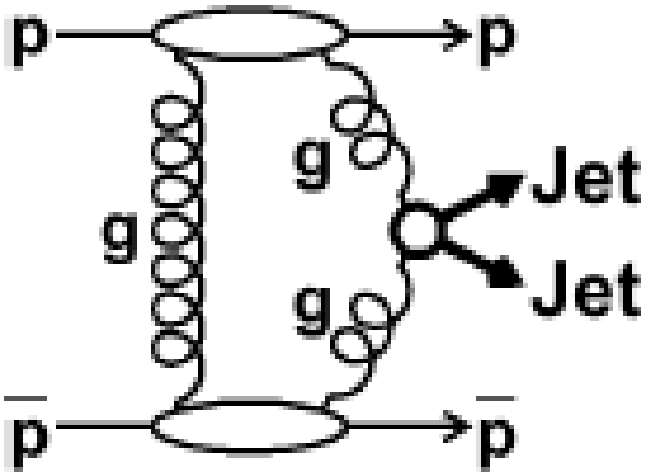
# CDF II Detector




| | | | |
|---|---|---|---|
| Tracking | – | Tracking Detectors | $\|\eta\| < 2.0$ |
| CCAL, PCAL | – | Calorimeters | $\|\eta\| < 3.6$ |
| RPS | – | Roman Pot Spectrometers | $0.02 < \xi < 0.1$<br>$0 < \|t\| < 2\ \text{GeV}^2$ |
| BSC | – | Beam Shower Counters | $5.4 < \|\eta\| < 7.4$ |
| MPCAL | – | MiniPlug Calorimeters | $3.5 < \|\eta\| < 5.1$ |

***used for gap detection***

# Exclusive Dijet Production




**Run I:**

CDF limit of

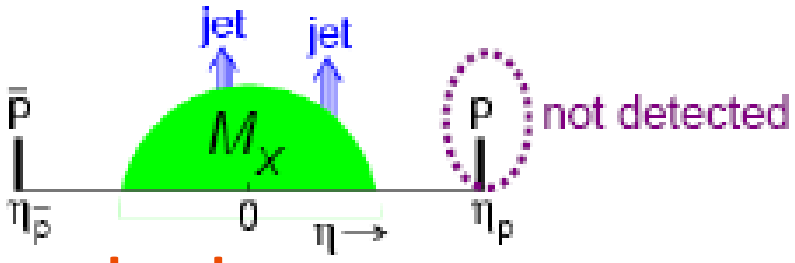
$\sigma_{excl}$<3.7 nb(95% CL)

**RUN II**

**Method:**

Select inclusive diffractive dijet events produced by DPE (Double Pomeron Exchange)

$$p+\bar{p} \rightarrow \mathbb{P}+\mathbb{P} \rightarrow \bar{p}+X(\geq 2 \text{ jets})+\text{gap}$$

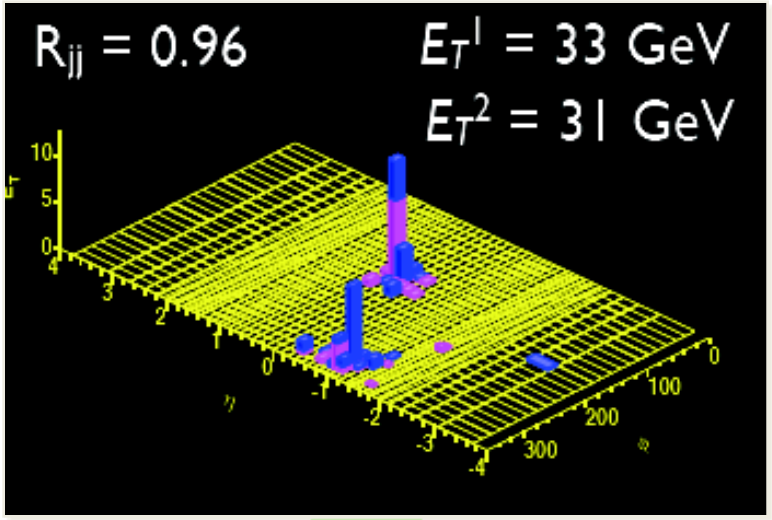


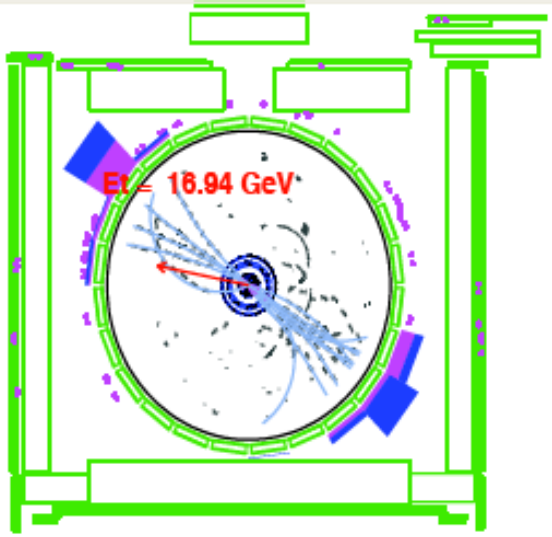

**Reconstruct**

$$R_{jj} = \frac{M_{jj}}{M_X}, \text{ where}$$

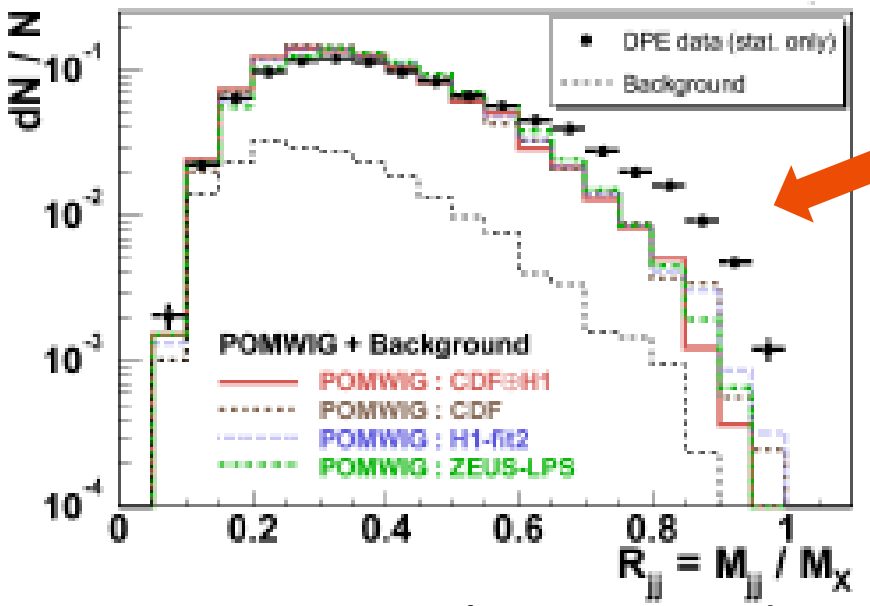
$M_{jj}$ - dijet mass, $M_X$ - mass of system X

# Observation of Exclusive Dijet Production




*PRD 77, 052004 (2008)*




Observe excess over inclusive DPE dijet MC's at high dijet mass fraction

Signal at $R_{jj}$=1 is smeared due to shower/hadronization effects, NLO $gg \to ggg, q\bar{q}g$ contributions

# Exclusive Dijet Cross Section

Signal MC ExHuME *CPC 175,232 (2006)*

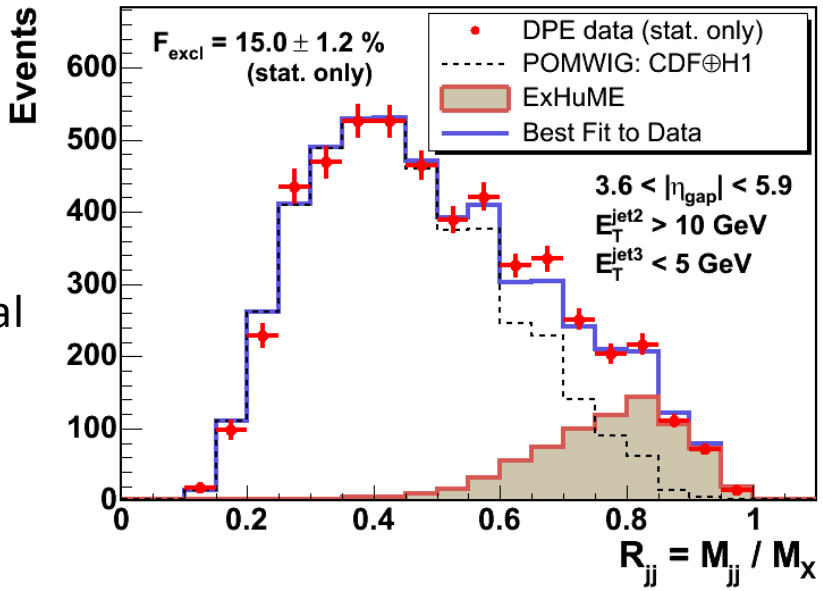
Exclusive DPE as input to DPEMC *CPC 167,217 (2005)*

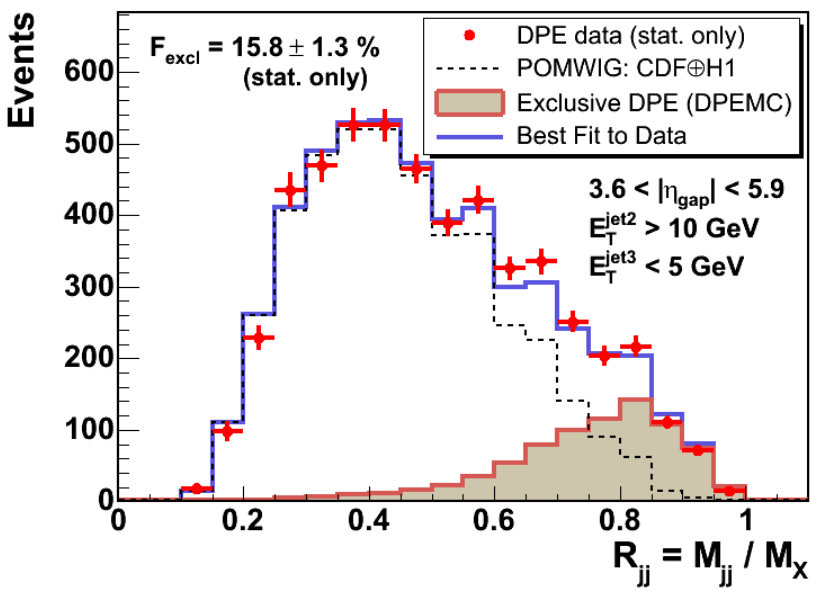
● data

▪▪▪▪ bkgd

▬ signal

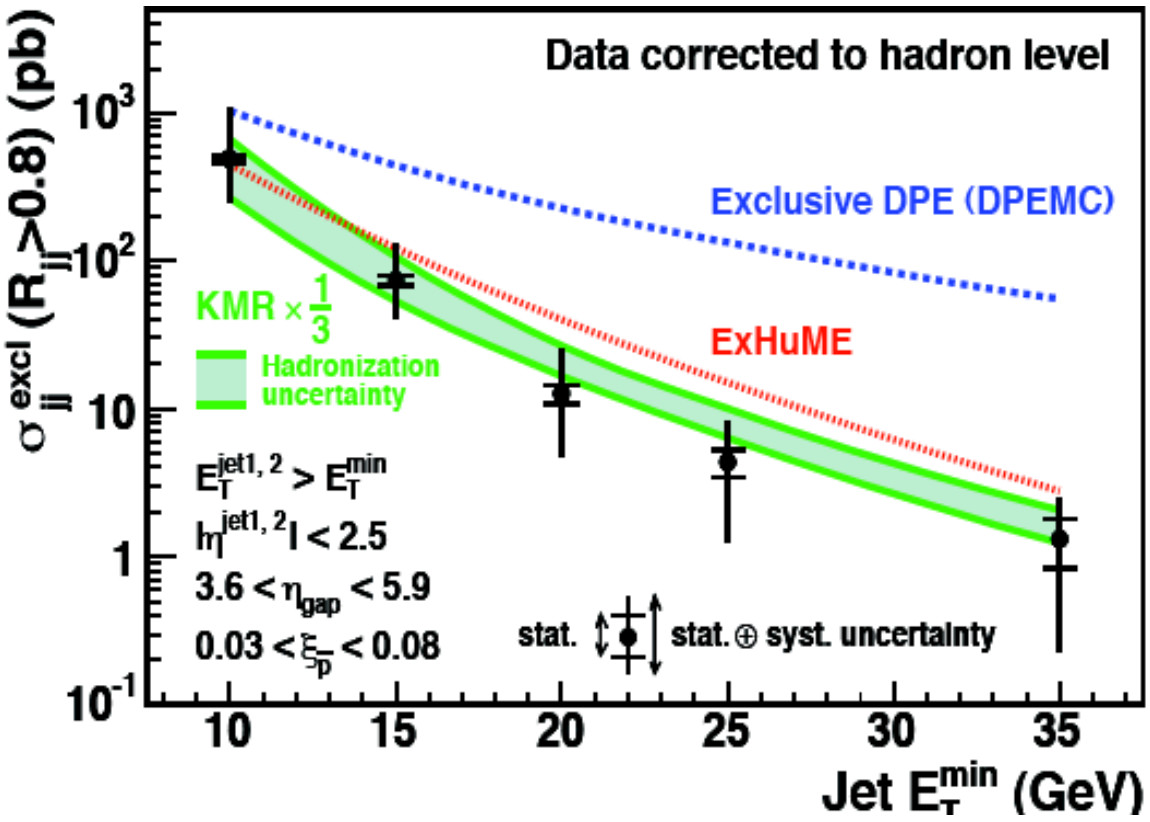
▬ fit




➔ Shape of excess described by exclusive dijet MC based on two models (ExHuME, DPEMC), shows good agreement

# Exclusive Dijet Cross Section

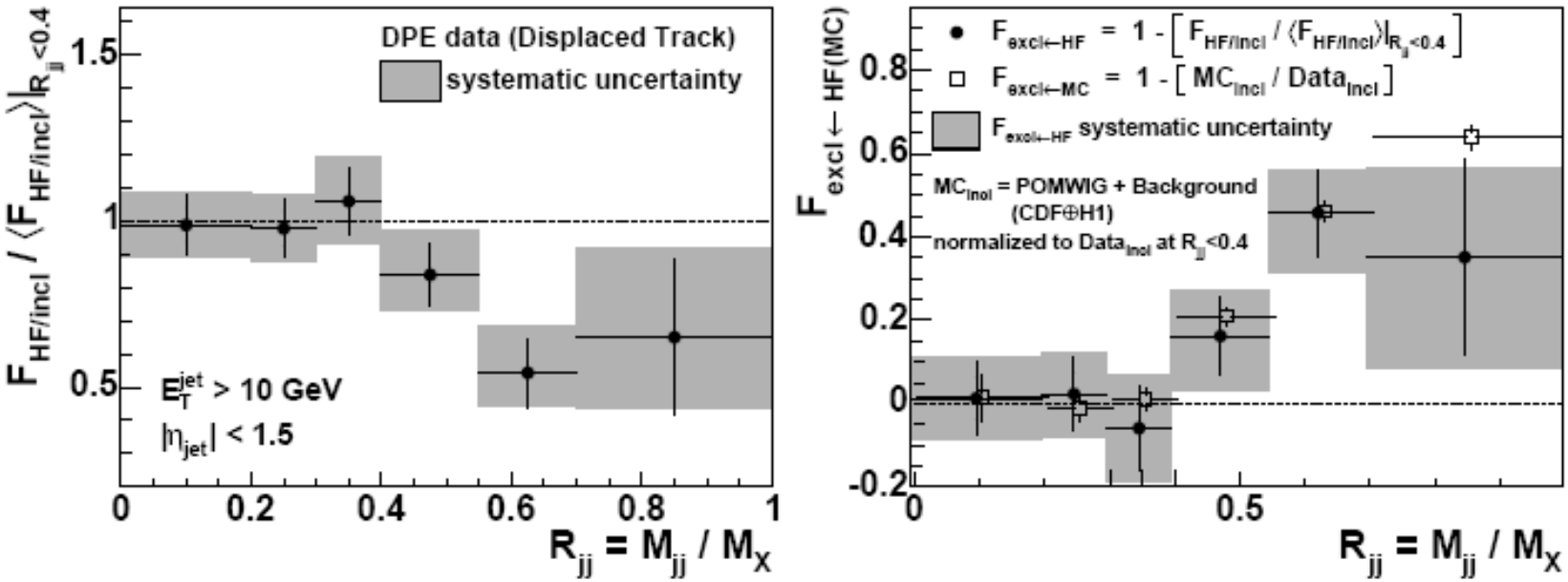



➔ Exclusive dijet cross section compared with MC based on two models (ExHuME, exclusive DPE DPEMC), cross section disfavors exclusive DPE model.

➔ Calculation by Khoze, Martin, and Ryskin consistent within its factor of 3 uncertainty. *Eur. Phys J C**14, 525 (2000).***

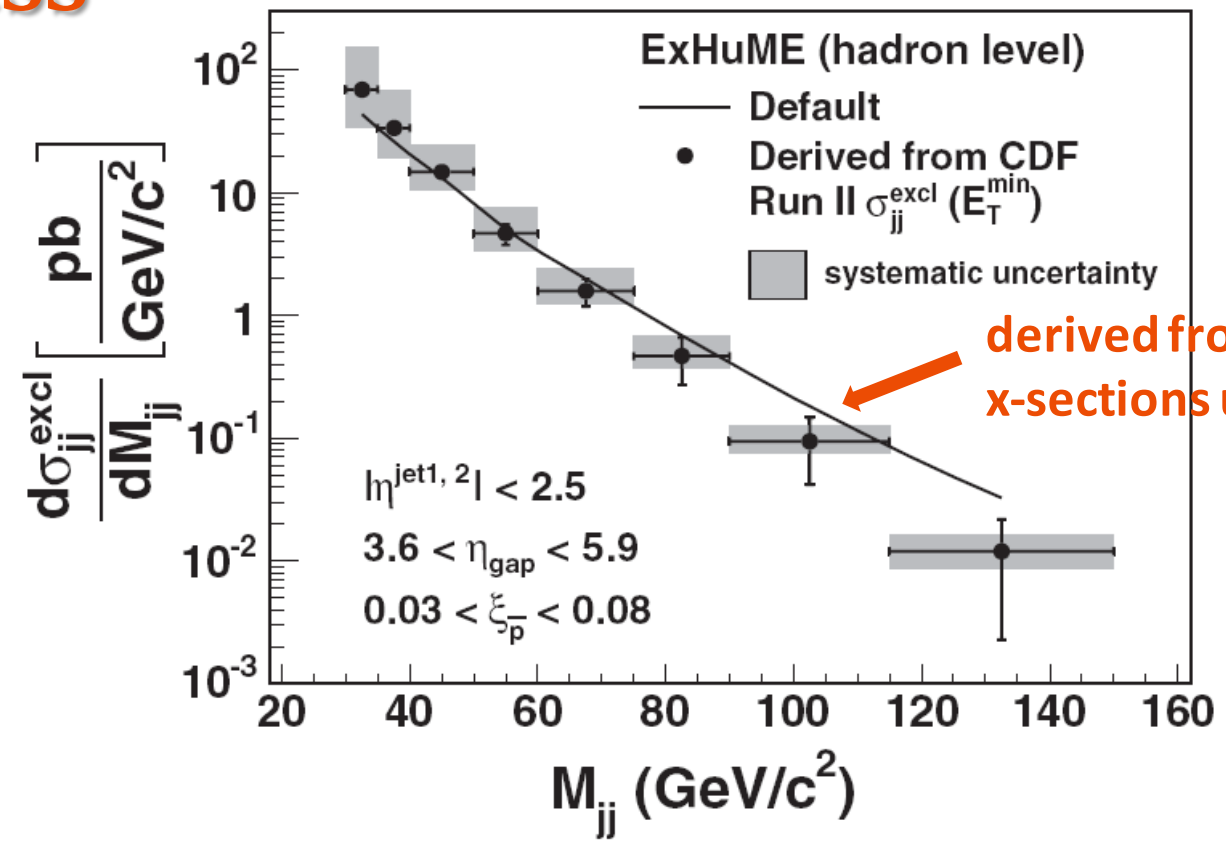
# Heavy Flavor Suppression

- LO exclusive $gg \rightarrow qq$ suppressed ($J_Z = 0$ rule)
- Look for **heavy flavor jet suppression** relative to inclusive dijets at high Rjj




Suppression of heavy flavor for $R_{jj} > 0.4$ is consistent in shape and magnitude with the results based on MC based extraction of exclusive dijet signal.

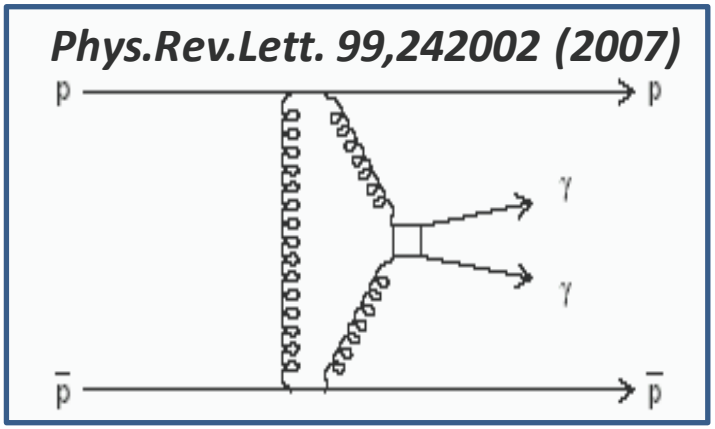
# Exclusive Cross Section vs Dijet Mass




derived from CDF excl. dijet x-sections using ExHuME

Stat. and syst. errors are propagated from measured cross section uncertainties using $M_{jj}$ distribution shapes of ExHuME generated data.

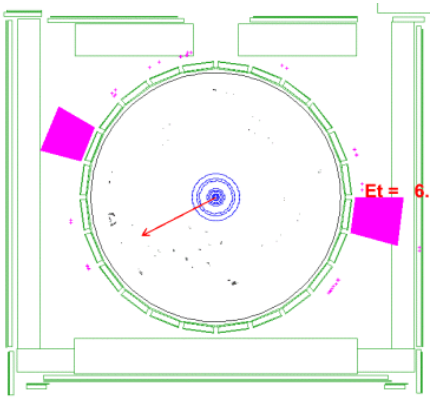
# Exclusive $\gamma\gamma$ Production




**3 candidates observed:**

**2 events are good $\gamma\gamma$ candidates**

**1 event is good $\pi^0\pi^0$ candidate**




$E_T(\gamma) > 5$ GeV

$|\eta(\gamma)| < 1.0$

**Theoretical Prediction:**

*V.A.Khoze et al. Eur. Phys. J C38, 475 (2005)*

$\sigma$ (with our cuts) = (36 +72 – 24) fb

= 0.8 +1.6 –0.5 events.

Cannot yet claim "discovery" as b/g study *a posteriori*,

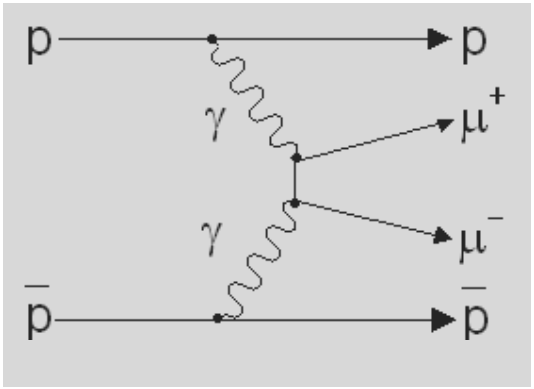
2 events correspond to $\sigma$ ~ 90 fb, agreeing with Khoze *et al.*

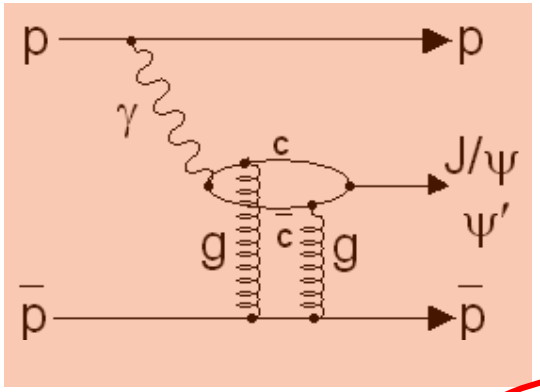
# Exclusive Dimuon Production

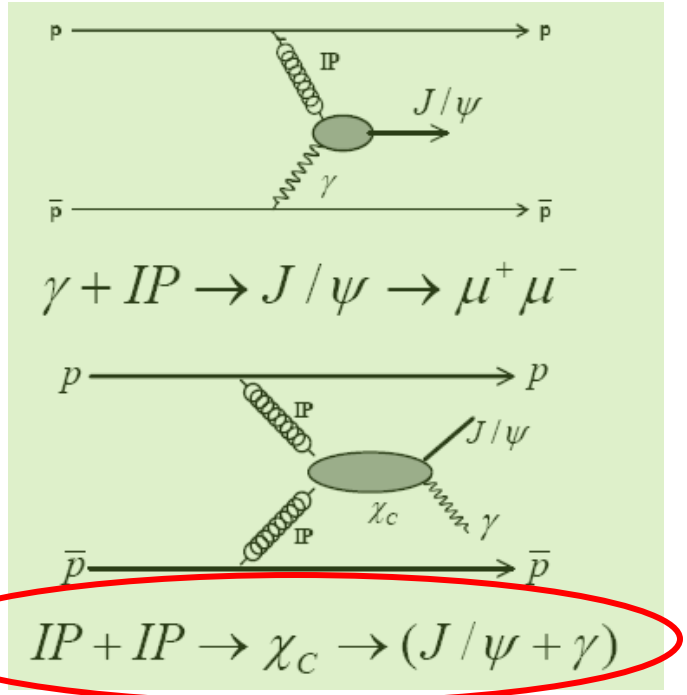
$$p + \bar{p} \rightarrow p + \mu^+ \mu^- + \bar{p}$$

$3\ \mathrm{GeV}/c^2 < M_{\mu\mu} < 4\ \mathrm{GeV}/c^2$

Many Physics Processes in this data:



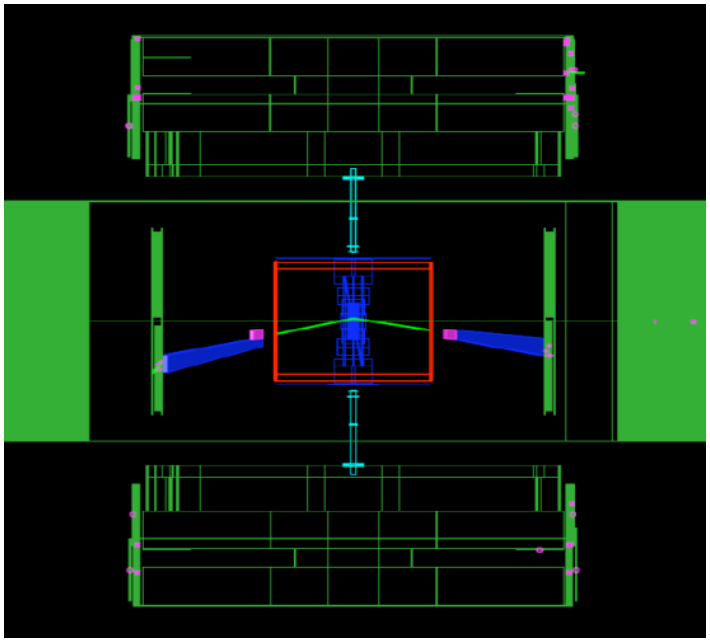



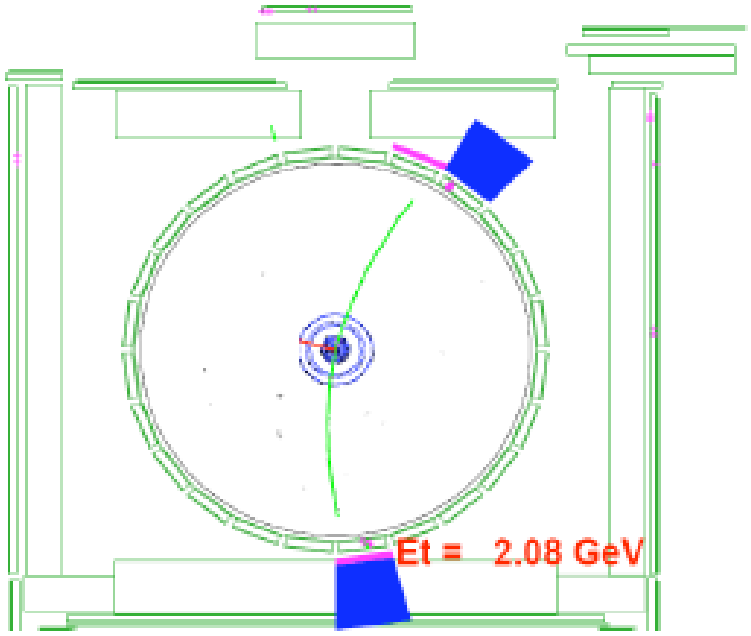




**exclusive $\chi_c$ in DPE**

*more information on exclusive central production in the talk by J. Pinfold*

# Exclusive Dimuon Production






$$p + \bar{p} \rightarrow p + \mu^+\mu^- + \bar{p}$$

$3\ \mathrm{GeV/c^2} < M_{\mu\mu} < 4\ \mathrm{GeV/c^2}$

**Trigger:**

muon + track + forward rapidity gaps in BSCs

2 oppositely charged muon tracks with $p_T > 1.4$ GeV/c, $|\eta| < 0.6$

$\varepsilon_{excl} \sim 0.093 \Rightarrow L = 1.48\ \mathrm{fb^{-1}}$ but $L_{eff} \sim 140\ \mathrm{pb^{-1}}$

# Exclusive J/ψ and ψ(2s)

## J/ψ production

243 ±21 events

$d\sigma/dy|_{y=0} = 3.92 \pm 0.62$ nb

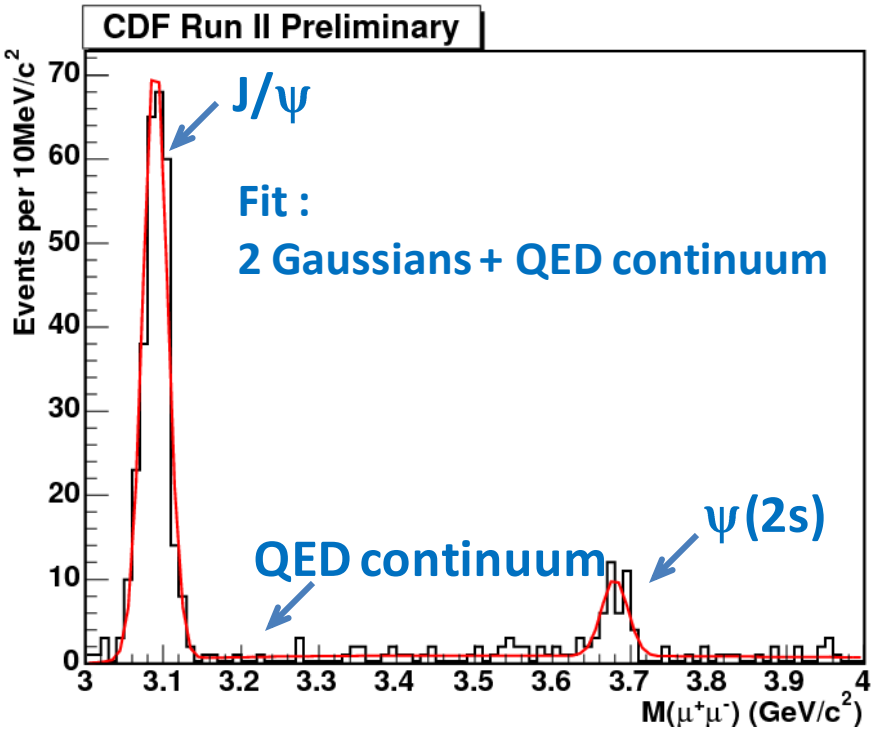
***Theoretical Predictions***

2.8 nb [Szczurek07,],

2.7 nb [Klein&Nystrand04],

3.0 nb [Conclaves&Machado05], and

3.4 nb [Motkya&Watt08].




## Ψ(2s) production

34±7 events

$d\sigma/dy|_{y=0} = 0.54 \pm 0.15$ nb

R = ψ(2s)/J/ψ = 0.14 ± 0.05

In agreement with HERA: R = 0.166 ± 0.012 in a similar kinematic region

# Exclusive $\chi_c \rightarrow J/\psi(\rightarrow \mu^+\mu^-)+\gamma$

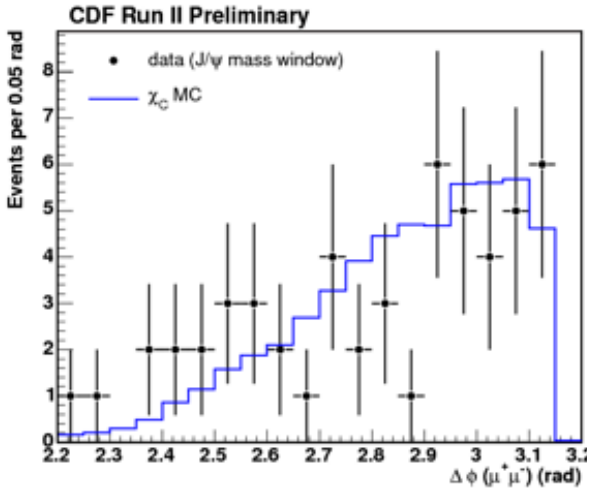
**request soft photon - EM tower energy** > 80 MeV ($|\eta|<2.1$)

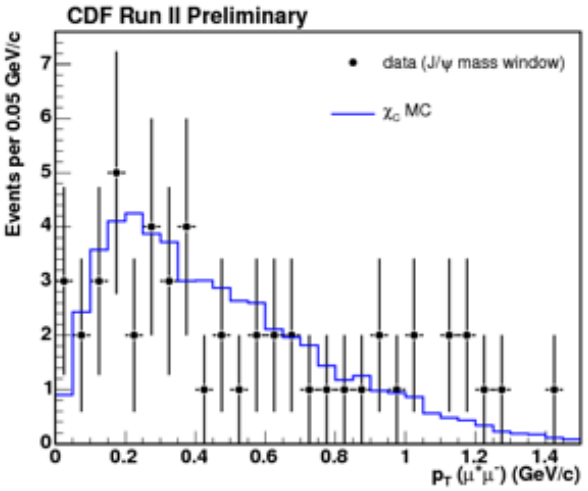
- If EM tower energy < 80 MeV the event is classified as exclusive photoproduction

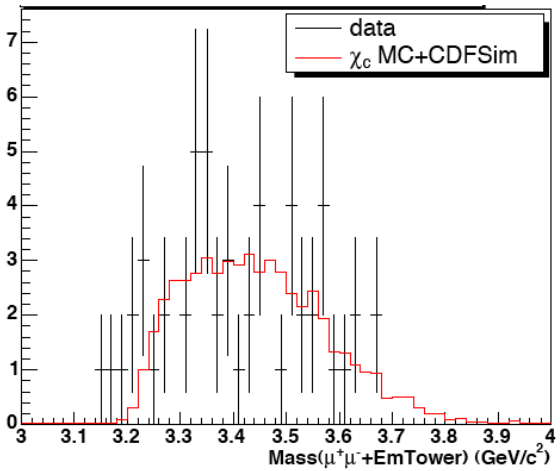
**reasonable agreement on kinematics with CHIC-MC**

- **Mass of the $\mu^+\mu^- + \gamma$ states compatible with $\chi_c$ mass**

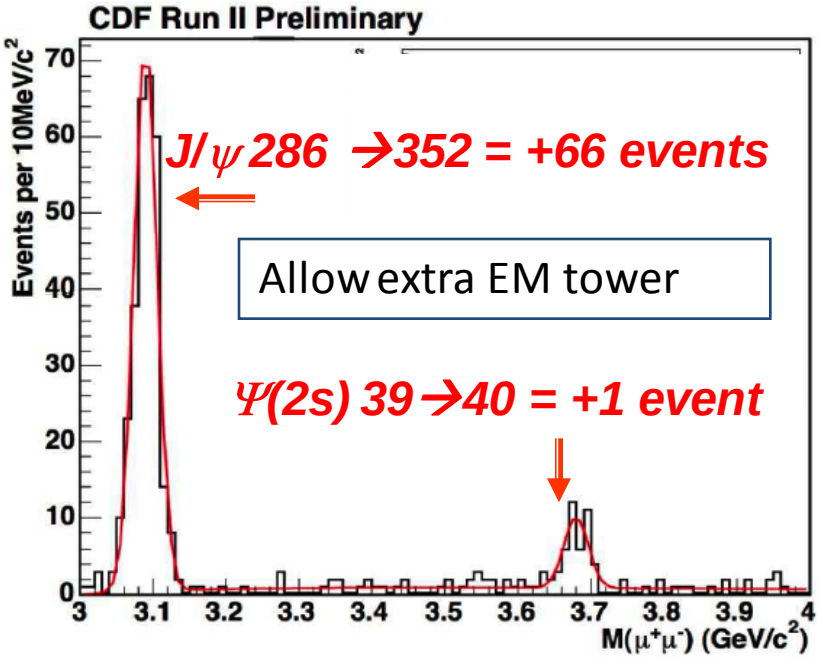
  $\chi_c{}^0(3415)$ & $\chi_c{}^2(3556)$ may be present – although spin-2 state is suppressed



# Exclusive $\chi_c \rightarrow J/\psi + \mu^+\mu^- + \gamma$




➔ Allowing EM towers ($E_T$ >80MeV)

large increase in the $J/\psi$ peak

minor change in the $\psi(2s)$ peak

↓

Evidence for

$\chi_c \rightarrow J/\psi + \gamma$ production

$d\sigma/dy|_{y=0} = 75 \pm 14$ nb,

compatible with theoretical predictions

160 nb (Yuan 01)

90 nb (KMR09)

# Conclusions

**The long-standing diffractive program at CDF continues to improve our understanding of the diffractive processes.**

Measurements of the exclusive production at CDF have been essential for calibrating prediction for exclusive Higgs production at the LHC:

observation of the exclusive dijet production

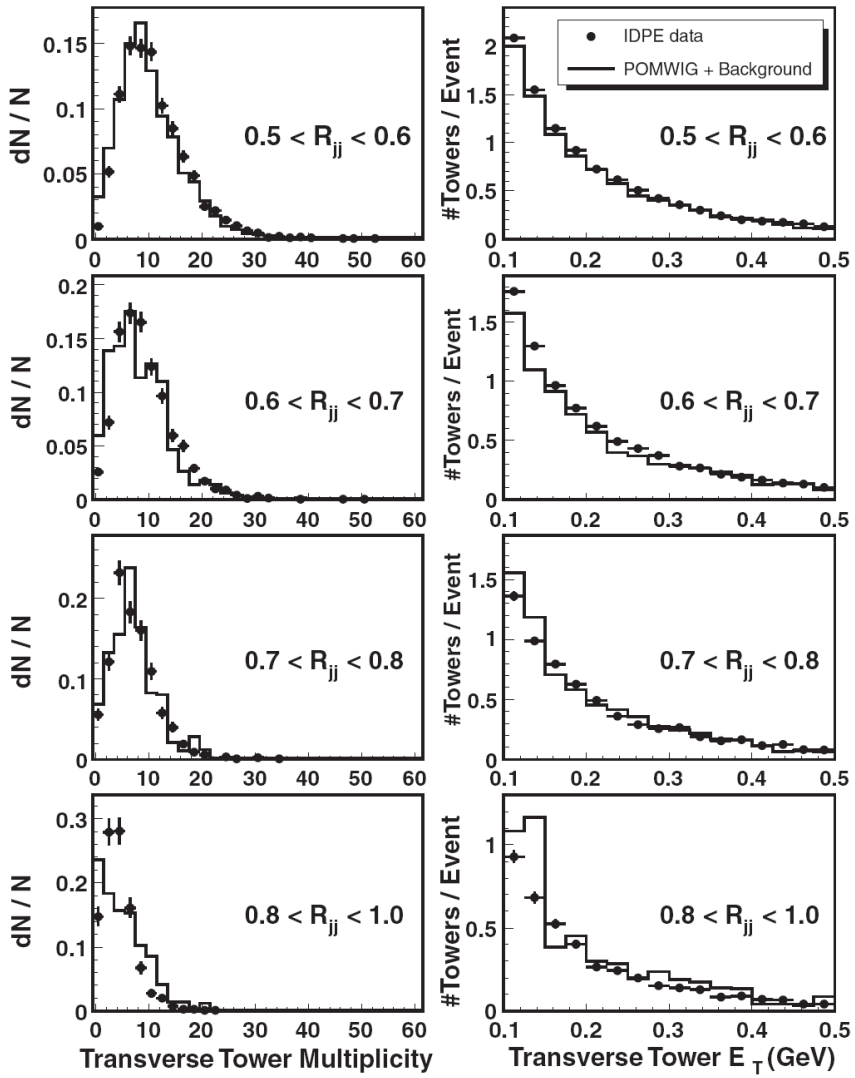
search for exclusive $\gamma\gamma$ production ( 3 candidates)

observation of the exclusive $\chi_{c0}$

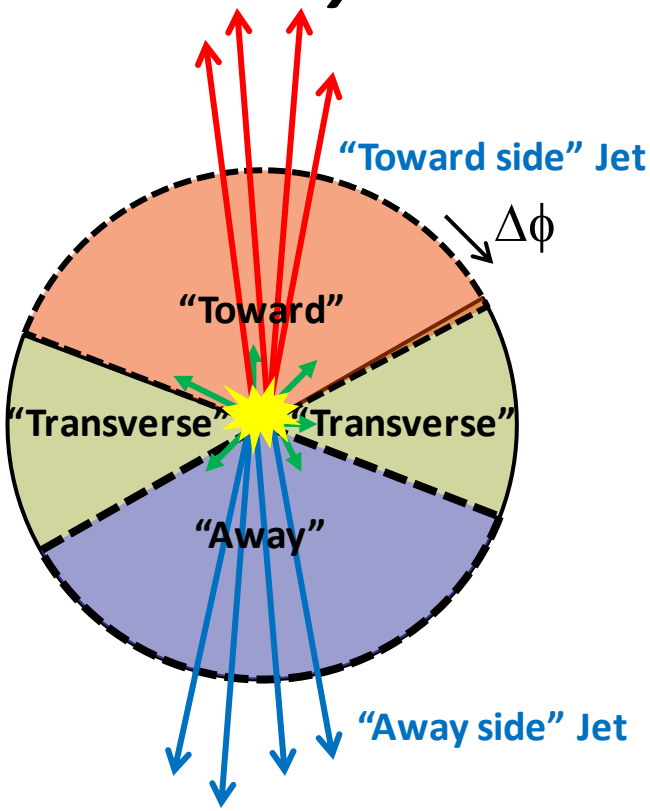
also of exclusive photoproduction of J/$\psi$, $\psi$(2s)

# Extra Slides

# Underlying Event

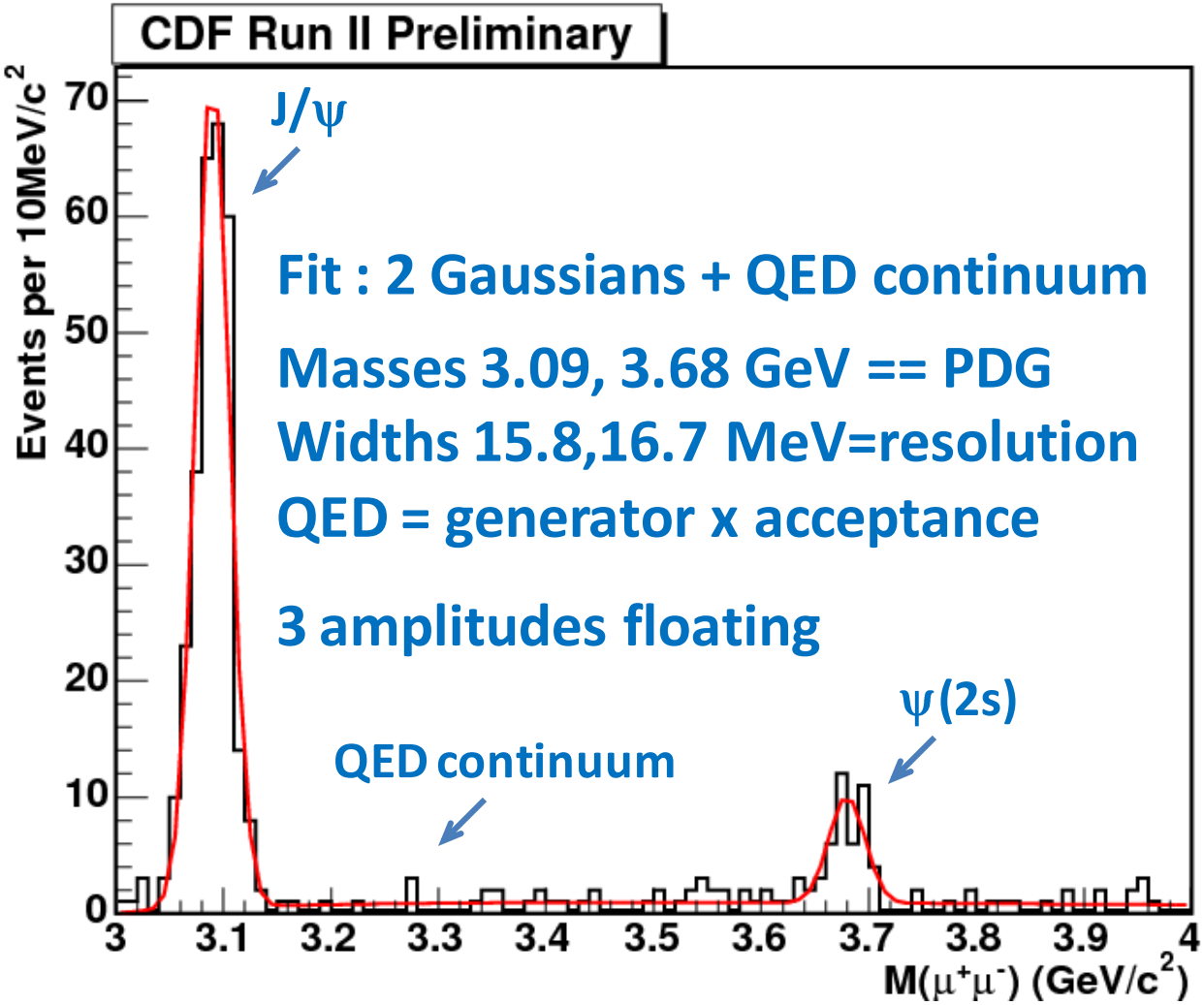



***Is it modeled correctly?***



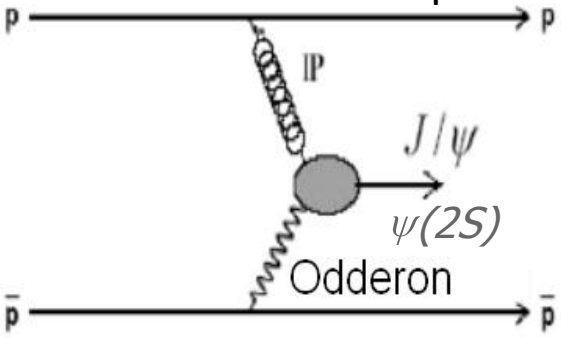

**The data and POMWIG+Background distributions in the transverse $\Delta\phi$-region, indicating that the UE is correctly modeled.**

# Exclusive J/ψ and ψ(2s)

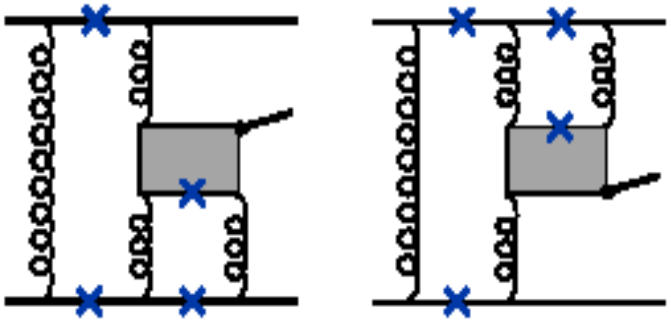


# Exclusive $\mu^+\mu^-$ and the Odderon

**Odderon**: C-odd partner of Pomeron → 3 gluons in a color-neutral state




LO diagrams →



The odderon would contribute to J/$\psi$, y $\psi$(2s) (&$\Upsilon$) peaks -not the $\chi_c$

**The J/ $\psi$ & $\psi$(2s) cross-sections agree with predictions**
$\rightarrow$ no significant odderon signal

**R (exp./theory)** $_{J/\psi}$ = 1.32 ± 0.41 , **R (exp./theory)**$_{\psi(2s)}$ = 1.15 ± 0.21
➔ **R(data/theory)** [combined J/$\psi$ &$\psi$(2s) ]= 1.19 ± 0.19

**Limit on odderon prod.** - R[(O-IP)$\rightarrow$V/($\gamma$-IP)$\rightarrow$V] < 0.34 (95% CL)